NEUTRAL CHARM DECAYS AT CLEO: SEARCHES FOR *CP* VIOLATION AND MIXING

R.M. HANS
for the CLEO Collaboration
University of Illinois, Loomis Lab, 1110 W. Green St.,
Urbana, IL 61801 USA

Recent CLEO results on neutral charm meson decays presented at the XXXVIth Rencontres de Moriond are discussed. We find no evidence of CP asymmetry in five different two-body decay modes of the D^0 to pairs of light pseudo-scalar mesons. We present a measurement of the mixing parameter $y_{CP} = -0.011 \pm 0.025 \pm 0.014$ by searching for a lifetime difference between the CP neutral $K^+\pi^-$ final state and the CP even K^+K^- and $\pi^+\pi^-$ final states. Finally, we describe the first measurement of the rate of wrong-sign $D^0 \to K^+\pi^-\pi^0$ decay: $R_{WS} = (0.43^{+0.11}_{-0.10} \pm 0.07)\%$.

1 Introduction and Motivation

The CLEO Collaboration, operating at the Cornell Electron Storage Ring, has been in existence for over 20 years. We discuss recent results on neutral charm meson decays from a data set of 9.0 fb^{-1} of symmetric e^+e^- collisions at $\sqrt{s} \approx 10.6$ GeV. One analysis uses a larger, 13.7 fb^{-1}, data set.

The study of mixing in the K^0 and B_d^0 sectors has provided a wealth of information to guide the form and content of the Standard Model. In the framework of the Standard Model, mixing in the charm meson sector is predicted to be small, making this an excellent place to search for non-Standard Model effects. Similarly, measurable CP violation (CPV) phenomena in strange and beauty mesons are the impetus for many current and future experiments. The Standard Model predictions for CPV for charm mesons are of the order of 0.1%, with one recent conjecture of nearly 1%. Observation of CPV in charm mesons exceeding the percent level would be strong evidence for non-Standard Model processes.

All of the analyses described in this paper use data collected with one configuration of the CLEO detector, called CLEO II.V, except for the analysis using the larger data set mentioned

above, which also uses data collected in the CLEO II configuration. The CLEO detector is described in detail elsewhere.[1] All simulated event samples were generated using GEANT-based simulation of the CLEO detector response.

2 General Experimental Method

All of the analyses presented in this paper use the same general technique, described below, except where noted. The D^0 candidates are reconstructed through the decay sequence $D^{\star+} \to D^0\pi_s^+$.[2] The charge of the slow pion (π_s^+) tags the flavor of the D^0 candidate at production. The charged daughters of the D^0 are required to leave hits in the silicon vertex detector and these tracks are constrained to come from a common vertex in three dimensions. The trajectory of the D^0 is projected back to its intersection with the CESR luminous region to obtain the D^0 production point. The π_s^+ is refit with the requirement that it come from the D^0 production point, and the confidence level of the χ^2 of this refit is used to reject background.

The energy release in the $D^\star \to D^0\pi_s^+$ decay, $Q \equiv M^\star - M - m_\pi$, obtained from the above technique is observed to have a width of $\sigma_Q = 190 \pm 2$ keV,[3] which is a combination of the intrinsic width and our resolution, where M and $M^\star$ are the reconstructed masses of the D^0 and $D^{\star+}$ candidates respectively, and m_π is the charged pion mass. The reconstruction technique discussed above has also been used by CLEO to measure the D^{*+} intrinsic width, $\Gamma_{D^{*+}} = 96 \pm 4 \pm 22$ keV (preliminary).[4]

3 *CP* Violation in D^0 Decay

Cabibbo suppressed charm meson decays have all the necessary ingredients for *CP* violation – multiple paths to the same final state and a weak phase difference. However, in order to get sizable *CP* violation, the final state interactions need to contribute non-trivial phase shifts between the amplitudes. Large final state interactions are a likely reason why the prediction for the ratio of branching ratios of $(D^0 \to K^+K^-)/(D^0 \to \pi^+\pi^-)$ yields a value roughly half of the observed value, hence these may provide a good hunting ground for *CP* violation.

We present results of searches for direct *CP* violation in neutral charm meson decay to pairs of light pseudo-scalar mesons: K^+K^-, $\pi^+\pi^-$, $K^0_S\pi^0$, $\pi^0\pi^0$ and $K^0_SK^0_S$.

3.1 Search for CP *violation in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decay*

The asymmetry we want to measure, $A = \left[\Gamma\left(D^0 \to f\right) - \Gamma\left(\overline{D^0} \to f\right)\right] / \left[\Gamma\left(D^0 \to f\right) + \Gamma\left(\overline{D^0} \to f\right)\right]$ can be obtained from the asymmetry $A^f = [\Gamma\left(D^{\star+} \to \pi_s^+ f\right) - \Gamma\left(D^{\star-} \to \pi_s^- f\right)] / [\Gamma\left(D^{\star+} \to \pi_s^+ f\right) + \Gamma\left(D^{\star-} \to \pi_s^- f\right)]$. The slow pion and D^0 are produced by the *CP*-conserving strong decay of the $D^{\star+}$, so the slow pion serves as an unbiased flavor tag of the D^0. The decay asymmetry can be obtained from the apparent production asymmetry shown above because the production of $D^{\star\pm}$ is *CP*-conserving.

The asymmetry result is obtained by fitting the energy release (Q) spectrum of the $D^{\star+} \to D^0\pi_s^+$ events. The D^0 mass spectra are fit as a check. The background-subtracted Q spectrum is fit with a signal shape obtained from $K^+\pi^-$ data and a background shape determined using Monte Carlo. The parameters of the slow pion dominate the Q distribution, so all modes have the same shape. We do the fits in bins of D^0 momentum to eliminate any biases due to differences in the D^0 momentum spectra between the data and the MC. The preliminary results are $A(K^+K^-) = 0.0005 \pm 0.0218(\text{stat}) \pm 0.0084(\text{syst})$ and $A(\pi^+\pi^-) = 0.0195 \pm 0.0322(\text{stat}) \pm 0.0084(\text{syst})$. The measured asymmetries are consistent with zero, and no *CP* violation is seen. These results are the most precise to date.[5]

3.2 *Search for* CP *Violation in* $D^0 \to K^0_S\pi^0$, $D^0 \to \pi^0\pi^0$ *and* $D^0 \to K^0_S K^0_S$ *decay*

This analysis[6] differs from the other analyses presented in this paper in some of its reconstruction techniques and in the data set used. The $\pi^0\pi^0$ and $K^0_S\pi^0$ final states do not provide sufficiently precise directional information about their parent D^0 to use the intersection of the D^0 projection and the CESR luminous region to refit the slow pion as described in the general experimental technique section. The $K^0_S K^0_S$ final state is treated the same for consistency. This analysis uses the data from both the CLEO II and CLEO II.V configurations of the detector.

The K^0_S and π^0 candidates are constructed using only good quality tracks and showers. The tracks (showers) whose combined invariant mass is close to the K^0_S (π^0) mass are kinematically constrained to the K^0_S (π^0) mass, improving the D^0 mass resolution. The tracks used to form K^0_S candidates are required to satisfy criteria designed to reduce background from $D^0 \to \pi^+\pi^- X$ decays and combinatorics. Candidate events with reconstructed D^0 masses close to the known D^0 mass are selected to determine the asymmetry, $A(f) = \left[\Gamma(D^0 \to f) - \Gamma(\overline{D^0} \to f)\right] / \left[\Gamma(D^0 \to f) + \Gamma(\overline{D^0} \to f)\right]$. The total number of D^0 and $\overline{D^0}$ candidates for a given final state is determined as follows. We fit the Q distribution outside of the signal region and interpolate the fit under the signal peak to determine the background in the signal region. We subtract the background in the signal region from the total number of events there to determine the total number of signal events. After background subtraction, we obtain 9099 ± 153 $K^0_S\pi^0$ candidates, 810 ± 89 $\pi^0\pi^0$ candidates, and 65 ± 14 $K^0_S K^0_S$ candidates.

The difference in the number of D^0 and $\overline{D^0}$ to a given final state is determined by taking the difference of the number of events in the signal region, and the asymmetry is obtained by dividing by the number of candidates determined above. This method of determining the asymmetry implicitly assumes that the background is symmetric.

We obtain the results $A(K^0_S\pi^0) = (+0.1 \pm 1.3)\%$, $A(\pi^0\pi^0) = (+0.1 \pm 4.8)\%$ and $A(K^0_S K^0_S) = (-23 \pm 19)\%$ where the uncertainties contain the combined statistical and systematic uncertainties. All measured asymmetries are consistent with zero and no indication of significant CP violation is observed. This measurement of $A(K^0_S\pi^0)$ is a significant improvement over previous results, and the other two asymmetries reported are first measurements.

4 Search for CP dependent lifetime differences due to $D^0 - \overline{D^0}$ Mixing

In the limit of no CP violation in the neutral D system we can write the time dependent rate for $D \to f$, where f is a CP eigenstate, as $R(t) \propto e^{-t\Gamma(1-y_{CP}\eta_{CP})}$ where Γ is the average D width, η_{CP} is the CP eigenvalue for f, and $y = y_{CP} = \frac{\Delta\Gamma}{2\Gamma}$ where $\Delta\Gamma$ is the width difference between the physical eigenstates of the neutral D, and y is the standard mixing parameter. We can then express y_{CP} as $y_{CP} = \frac{\tau_{\overline{CP}}}{\tau_{CP+}} - 1$ where $\tau_{\overline{CP}}$ is the lifetime of a CP neutral state, such as $K\pi$, and τ_{CP+} is the lifetime of a CP even state, such as KK or $\pi\pi$. Thus to measure y_{CP} we simply take the ratio of the lifetimes of $D^0 \to K\pi$ to $D^0 \to KK$ and $\pi\pi$. Since the final states are very similar, our backgrounds are small, and cross-feed among the final states is negligible, many of the sources of uncertainty cancel in the ratio. For a discussion of the case allowing CP Violation see, for example, reference.[7]

We fit the proper time distributions of the signal candidates selected in a narrow region around the D mass with an unbinned maximum likelihood fit. The probability for a candidate to be signal is determined by its measured mass, and is based on the fit to the mass distributions. Background is considered to have contributions with both zero and non-zero lifetimes.

We calculate y_{CP} separately for the KK and $\pi\pi$ samples. Our preliminary results are $y_{KK} = -0.019 \pm 0.029(\text{stat}) \pm 0.016(\text{syst})$ and $y_{\pi\pi} = 0.005 \pm 0.043(\text{stat}) \pm 0.018(\text{syst})$. We form a weighted average of the two to get $y_{CP} = -0.011 \pm 0.025(\text{stat}) \pm 0.014(\text{syst})(\text{preliminary})$.

This result is consistent with zero, and with previous measurements of y_{CP}.[8]

5 First Observation of Wrong-Sign $D^0 \to K^+\pi^-\pi^0$ Decay

The $D^0 \to K\pi\pi^0$ candidates are reconstructed using the selection criteria described in Section 2, with additional requirements specific to this analysis. In particular, π^0 candidates with momenta greater than 340 MeV/c are reconstructed from pairs of photons detected in the CsI crystal calorimeter. Backgrounds are reduced by requiring specific ionization of the pion and kaon candidates to be consistent with their respective hypotheses.

The right–sign mode was recently studied by CLEO[9] and found to have a rich Dalitz structure consisting of $\rho(770)^+$, $K^*(892)^-$, $\overline{K^*}(892)^0$, $\rho(1700)^+$, $\overline{K_0}(1430)^0$, $K_0(1430)^-$, and $K^*(1680)^-$ resonances and non-resonant contributions. Recent theoretical predictions based on U-spin symmetry arguments[10] suggest that the wrong sign (WS) channel will have a different resonant substructure than the right sign (RS). We allow for different average WS and RS efficiencies in the calculation of the WS rate: $R_{WS} = (\bar{\varepsilon}_{RS}/\bar{\varepsilon}_{WS}) \cdot (N_{WS}/N_{RS})$.

The ratio of yields is measured by performing a maximum likelihood fit to the two-dimensional distribution in $m(K\pi\pi)$ and Q. The signal distribution in these variables is taken from the RS data. The background distributions are determined using a large Monte Carlo sample, which corresponds to approximately eight times the integrated luminosity of the data sample. The Q–$m(K\pi\pi^0)$ fit yields a WS signal of 38 ± 9 events and a ratio $N_{WS}/N_{RS} = 0.43^{+0.11}_{-0.10}\%$. The statistical significance of this signal is found to be 4.9 standard deviations.

The average efficiency ratio is determined using a fit to the Dalitz plot variables $m^2(K^+\pi^-)$ and $m^2(K^+\pi^0)$ in the WS data. In this fit, the amplitudes and phases are initialized to the RS values, and those corresponding to the $K^*(892)^+$ and $K^*(892)^0$ resonances are floated relative to the dominant $\rho(770)^-$ and other minor contributions. Combining the square of the fitted amplitude function with a parameterization of the efficiency determined using a large non-resonant Monte Carlo sample, we measure an average efficiency ratio of 1.00 ± 0.02(stat).

We measure the wrong sign rate to be $R_{WS} = 0.43^{+0.11}_{-0.10}$ (stat) ± 0.07 (syst)% (preliminary). This measurement can be used to obtain limits on R_{DCSD} as a function of y' (see reference [11]).

References

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